NEW YORK ,NEW HAVEN, AND HARTFORD RAILROAD, BRIDGE-TYPE CIRCUIT BREAKERS

HAER No. CT-142-C

(Electrification System, Bridge-Type Circuit Breakers)
Long Island Sound shoreline between
Stamford and New Haven
Cos Cob
Fairfield County
Connecticut

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PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
Northeast Region
Philadelphia Support Office
U.S. Custom House
200 Chestnut Street
Philadelphia, P.A. 19106

HISTORIC AMERICAN ENGINEERING RECORD

NEW YORK, NEW HAVEN & HARTFORD RAILROAD, BRIDGE-TYPE CIRCUIT BREAKERS

(Electrification System, Bridge-type Circuit Breakers)

HAER No. CT-142-C

Locations: Long Island Sound shoreline between Stamford and New Haven.

Anchor Bridge #310: Spanning New York, New Haven & Hartford Railroad tracks 820 feet east of Cos Cob Station, Greenwich, Fairfield County, Connecticut.

Anchor Bridge #374: Spanning New York, New Haven & Hartford Railroad tracks at Canal Street, Stamford, Fairfield County, Connecticut.

Anchor Bridge #465: Spanning New York, New Haven & Hartford Railroad tracks 1000 feet east of Darien Station, Darien, Fairfield County, Connecticut.

UTM Coordinates:

Bridge	Zone	Easting	Northing
310	18	617940	4542830
374	18	623070	4545020

Quad: Stamford, Connecticut 1:24000

Bridge	Zone	Easting	Northing
465	18	628640	4548240

Quad: Norwalk South, Connecticut 1:24000

Date of Construction: Anchor Bridge #310, circa March 1907; Anchor Bridges #374 and #465 were added during expansion of service to New Haven in 1914.

System Design Engineers: E. H. McHenry, William S. Murray, Calvert Townley

Manufacturer: Westinghouse Electric and Manufacturing Company, Switchgear Engineering Department, East Pittsburgh, Pennsylvania

Present Owner: Metro-North Commuter Railroad
345 Madison Avenue
New York, NY 10017

Present Use: Currently operating and in use. To be replaced by 1996.

Significance: These circuit breakers provide electrical fault protection for individual track sections of the Metro-North power transmission system. They are integral components of the first long distance railroad electrification project built in the United States. Although they were modified in 1914 and 1942, their basic design has remained the same over eighty-seven years of relatively trouble-free service. They are a prime example of functional and adaptable engineering design and construction.

Project Information: This documentation was initiated April 1, 1994 in accordance with the Memorandum of Agreement by the Connecticut Department of Transportation as a mitigating measure prior to replacement of the circuit breakers. The breakers will be offered to appropriate museums for preservation.

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Introduction

On January 8, 1902, a tragic train wreck killed seventeen people in a tunnel which serviced New York City's Grand Central Station. The disaster was caused by poor visibility; smoke and exhaust steam from coal-fired locomotives obscured the signals that controlled trains. Public outrage resulted in legislation which would ban steam trains from New York City after 1908. The New York Central and New York, New Haven & Hartford Railroads reacted to the restriction with a plan for electrification of their lines which serviced the city.

The concept of electric traction was not new to the New Haven. The railroad had been experimenting with electric propulsion systems since 1895 (Withington 1931:3). The trials demonstrated that electric operation could be economically advantageous in high traffic areas. At the time of the tunnel wreck, New Haven engineers were working on a long-term electrification scheme that included most main lines. The legislative mandate and the disaster undoubtedly hastened implementation of electric service.

In 1904 The New York, New Haven & Hartford Railroad decided to electrify its line from Stamford, Connecticut, to Woodlawn, New York. At Woodlawn, New Haven trains would continue to New York City over the electrified lines of the New York Central. The combined length of electrified right-of-way totaled 33 miles. Revenue service started in June of 1907. (Westinghouse Electric and Manufacturing Company, (WE&MC) 1924:14). This was the first trunk-line electrification in the United States[a] (Greenhill 1985:86). The outcome was satisfactory and from 1911 to 1914 the railroad extended electric service eastward 45 miles to New Haven. Simultaneous westward expansion included freight yards and the New Haven's Harlem River Branch from New Rochelle to the Harlem River. (Information for Inspection Party - New York and Vicinity 1921:1).

Development of Power System Components

During the latter part of the nineteenth century George Westinghouse promoted and developed an alternating-current (AC) electrical system that was far superior to Edison's direct-current (DC) system for transmitting power over long distances. With prudent acquisition of

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[a] On July 3, 1895 the New York New Haven & Hartford opened an electrified short branch line between Nantasket Beach and Pemberton, Massachusetts. The section of track was 4.95 miles long. This is the basis for the New Haven's claim to be the first electrified railroad in the United States. The New Haven's run occurred two days after the opening of the electrified Baltimore and Ohio tunnel in Baltimore. An extant photograph of the Baltimore & Ohio run on July 1, 1895, shows an electric locomotive backed up by a steam engine. Full electric operation in the tunnel did not begin until the following May.

patent rights and by hiring creative engineering talent, Westinghouse was able, by the turn of the century, to offer a comprehensive alternating-current system for railroad traction. Commercial use of alternating-current at this time was practically non-existent. (Reich 1975:45). New Haven's decision to go with an alternating-current system was revolutionary but based on sound scientific principles. Alternating-current was shown to be superior in theory for most applications, but it had not been around long enough to be considered mature technology. General Electric and Westinghouse submitted proposals for the New Haven Electrification. The Westinghouse Electric and Manufacturing Company was selected to design and build the great majority of components for a high-voltage, alternating-current system.

Several major systems were built to electrify the New Haven. A generating plant and control system to monitor and regulate electrical power was built. Power was delivered to locomotives via an overhead catenary and trolley wire system. A high-voltage feeder wire system was installed to provide electricity to stations and railroad shops. Finally, a signalling and communications system tied the whole system together and enabled safe and timely operation.

Power for the New Haven system was provided from a plant built at Cos Cob, Connecticut (Stewart 1993:1-98). The plant was the first facility to generate 11,000 volt, 25 cycle alternating-current for railroad traction power in the United States. Power was fed into the system at a location identified as anchor bridge #310[b]. (Photograph of Cos Cob anchor bridge). The railroad enlarged the original power plant between 1911 and 1912 to provide additional power for its eastward expansion.

The Westinghouse/New Haven scheme was a departure from the accepted standards and proven components of the period, it involved concepts that were unproven outside a laboratory. It also required equipment that was untested in large scale railroad operations. The high-voltage alternating-current scheme also posed compatibility problems with the New York Central's third-rail, 600 volt direct-current system.

[b] Anchor bridges are sturdy, well braced, frames which provide tensioning support for the overhead catenary wires. (Photograph of view east of Anchor Bridge #310 at Cos Cob). At each end of the anchor cross truss, an 11,000-volt 5 kilowatt, shunt transformer was located. One transformer was connected to a bus-bar which ran around the circuit breakers. The other transformer was connected directly to one of the "power" feeders. The power feeder formed one leg of the third phase of the generating system. Thus, in the event of damage to the trolley-wire section, power for operating switches and signals was still available.

Several professional reputations were at stake and so were millions of dollars in capital investment. New Haven's engineering staff, particularly Calvert Townley and William S. Murray, was committed to years of hard work to solve the practical problems of an alternating-current system (McHenry 1907:184). Contributions were made by Benjamin G. Lamme, a prominent Westinghouse engineer who bridged the gap between theory and practical application to design functional equipment and traction motors (Withington 1931:6). The stakes were considerable -- success would provide the solution to the problem of powering heavy trains at high speeds over great distances with electricity (Withington 1931:4). The system, which entered revenue service in 1907, set the standard for power characteristics in American Railroad electrification: single-phase alternating-current at 11,000 volts and 25 cycles. It was obvious from the start that some machines and systems didn't work as planned and the period from 1907 to 1924 was a time of continuing development and improvement of system components.

Oil-filled, Bridge-type Circuit Breakers

Circuit breakers are automatic self-actuated or remotely controlled devices capable of switching electrical power on and off. They serve to isolate sections of the railroad line from the system as a whole when electrical faults occur. The bridge-type circuit breakers are located on anchor bridge structures in the towns of Greenwich, Darien and the city of Stamford (Figures 1, 2 and 3). This report was organized to detail the changes in circuit breaker operation and design over the eighty seven years of service. It focuses on oil-filled circuit breakers (Figure 4) which are installed on supports for the overhead trolley system defined as anchor bridges (Photographs of Darien and Stamford anchor bridges). The Westinghouse and New Haven Engineers addressed the problems created by a requirement to clear frequent short-circuits of relatively large magnitude as compared to existing commercial experience. Their efforts led to the development of new electrical and mechanical technology (Christmas 1982:7). Several devices were tried before a satisfactory solution was found (Withington 1931:7).

Interrupting circuits which are carrying heavy electrical loads is difficult and dangerous without properly designed equipment. When a switch is used to break a circuit under load at the high voltages and currents typically used in railroad operation, electricity will form an arc which ionizes the air around the switch points as they open. This ionized air conducts the electric current which continues to flow across the air gap between switch contact points. In addition to interfering with shutting off the current flowing in the line, the arc is destructive to switch components. To snuff out this conducting arc and positively break the circuit, several methods are used. Modern breakers enclose switch points in a vacuum; without air to ionize, no conducting arc can form. However, at the turn of the century, the materials capable of maintaining a long-term vacuum seal on a breaker housing did not exist. Early electrical technology solved this problem by immersing the switch contact points in an insulating oil bath. Under normal conditions, oil does not form a conducting path for the arc, making it possible to cleanly interrupt the flow of current in a fraction of a second.

As technology advanced, the breakers were improved. Other design features that enable the Westinghouse bridge breakers to minimize arc formation are accelerating springs which forcefully and swiftly drive the switch contacts apart and the patent "de-ion" grid (Photograph of "de-ion grid" contacts). The grid is a stack of alternating metal and insulating plates which form the stationary part of the switch contacts. By alternating insulating and conducting components, any arc that may form is broken into segments which are snuffed by the surrounding oil. The new accelerating springs and the "de-ion" grid contacts were added to the original breakers during a major rebuild in 1942.

<u>Breakers in Operation</u>

The original power distribution system was supplied from the Cos Cob Power plant through two high-tension buses. One supplied three-phase current to a substation at Port Morris and the other supplied single-phase current to run locomotives. For the propulsion system, one leg of this system was grounded to the track rails along the right-of-way; the second leg supplied the outgoing feeders which were connected directly to the trolley and completed a single phase circuit through any locomotive operating on the system. The third leg was connected to a feeder which was carried along the right-of-way to supply power for local purposes such as station lighting or repair and maintenance shop power[c].

By insulating the trolley wires from one another and creating isolated track sections, the railroad could disconnect any section of wire in the event of an electrical fault or emergency. Power could be maintained on parallel tracks to allow operations to continue. Circuit breakers capable of isolating specific sections of track were generally controlled from interlocking towers (Reich 1975:50).

In the event of a derailment or severe damage to the power feed lines or catenary, the resulting short circuit could overload and do serious thermal or mechanical damage to the main generators at the power plant. The ability to instantly cut off power to the system was crucial to safe operation. To prevent damage in the event of a system fault, circuit breakers were installed at the power house and key points along the right of way. In 1907, these were essentially remotely operated switches which could cut off the power to specific track sections if current exceeded safe operating values (Coster 1908:15).

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[c] This circuit design resulted in 'unbalanced operation'. If there is current drawn on only one leg of a three-phase generator, the theoretical capacity is only 57.7 per cent of that which can be obtained with balanced three-phase operation. On the New Haven, power drawn from the third leg feeders for local use along the right-of-way for ancillary facilities raised the percentage considerably.

The original breaker configuration did not include current sensing circuits which would detect an overload and automatically trip the breaker. A secondary switchboard within the Cos Cob powerhouse controlled single-phase sectionalizing bridge-type circuit breakers. 25 cycle AC power for substation switch control was provided by a motor-generator set (WE&MC 1924:16). Remote breakers were manually operated by power house electricians who constantly monitored ammeters which indicated the amount of current flowing in the system (Golino 1994). When current exceeded safe operating standards, control signals would be transmitted to trip the appropriate breakers. When the fault was cleared, tower operators could close the breakers by remote control.

When the power plant went on-stream in 1907, its three rotating-field, 3-phase generators were unable to achieve their guaranteed output of 9000 kilowatts. Design problems produced unbalanced currents and stray magnetic fields; generators overheated when run at normal operating conditions. It took four rebuilds before they operated to specification (Haelig 1965:12). Westinghouse engineers finally solved the problem by adding an extra, short-circuited winding in the rotating field. This kept stray currents within limits and diminished the overheating problem but it created difficulties with the system circuit breakers.

Alterations to the Original Breakers and Operating System

After a fourth generator was added in 1908 and the power plant was running at full total rated power of 12,330 kilowatts, the engineers discovered that the system circuit breakers were unable to handle the increased current loads. If a trolley shorted to ground, and the appropriate breaker was tripped, the insulating qualities of the oil were not sufficient to inhibit the arc. The resulting arc would extend from the contacts right through the insulating oil bath to the walls of the circuit breaker tank -- failure of circuit breakers caused many delays. This problem was corrected by using the feeder wires to supply power to the trolley at Port Chester, 3.65 miles west, and Stamford, 3.83 miles east of Cos Cob. No power was fed to the trolley at Cos Cob anchor bridge #310. The resistance in 7.48 miles of feeder wire moderated and controlled power surges at a cost of a 2 percent loss of system power (Haelig 1965:16). The railroad operated with this system from around mid-1908 until electrification was extended to New Haven in 1914 (Figure 5).

At the time of system expansion in 1914, the distribution system was revised to form the present 3-wire system. The circuit diagram was published by Westinghouse in 1924 (Figure 6). Until Cos Cob shut down in 1986, its power flowed through Westinghouse type C.O.-22 breakers into two parallel 3-phase buses. 3-phase power for local service and ancillary railroad service along the right-of-way was tapped off phase 1 of these buses. The traction load was taken off phases 2 and 3 and directed through another set of C.O.-22 breakers into six oil insulated, water cooled 11,000 volt to 22,000 volt, autotransformers which were rated at 7200 kv-a each; neutral points of the transformers were connected to the rails (WE&MC 1924:22).

The problem with the new system was that it could generate currents far in excess of loads which the circuit breakers could safely handle. Rather than upgrading the breakers, the engineers reduced current in the system to a value which the breakers could control.

The innovative changes limited current, when it was necessary, by inserting resistance into the circuit. Before leaving the plant, the power feed was directed through another set of C.O.-22 breakers. Power then flowed through trolley and feeder breakers which normally paralleled and short-circuited resistance grids. In the event of a short-circuit on the line, a selective relay located at the substation closest to the fault sensed abnormal current flow and closed a trip circuit to the breaker connected to the malfunctioning track section. The tripping circuit normally did not have any current flowing through it, so the breaker was not activated. Simultaneously, the circuit breakers which short-circuited the resistance grids located at the power plant opened consecutively, sequentially adding additional resistance into the circuit to control the current (Gilles 1994).

When all the resistance grids were in series with the load, the current flowing in the system was reduced to about 2500 amperes, a level which could be handled by the oil-filled circuit breakers installed on the anchor bridges. An 11,000 volt control circuit extending along the right-of-way then activated and this energized the trip coils of the local bridge-type circuit-breakers located on an anchor bridge which was feeding the short or fault (Haelig 1965:18). The 11,000 volt control voltage was stepped down through a transformer to 440 volts to trip the breaker. The bridge breaker would then open and cut out the section of line which it controlled. As soon as the defective line was isolated, the C.O.-22 breakers back at the power house would close and short out the resistance grids, returning power to the unaffected sections of the system. The system was designed with redundant or back-up components so that a failure in an element could be bypassed (Haelig 1965:18).

In 1937 Westinghouse developed a retrofit and modernization package for their oil-filled bridge-type circuit breakers. The New Haven rebuilt and modernized its breakers in 1942. The manual for rebuilding the breakers is included in this report (Figure 8). At that time they were modified to interrupt faults up to 16,000 amperes at the point of their installation. The remote grid resistors at Cos Cob no longer had to be inserted into the system to limit current and they were scrapped. The rebuild required complete dismantling of the breakers to add on several new features. Contacts were changed to the "De-ion Grid" types. These new contacts sandwiched alternating layers of insulating Micarta[d] and copper alloy to form a switch point contact which broke up the arc and improved operation (Manual 1940:2). Other features added included

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[d] Micarta is a Westinghouse trademark for an insulating board made of layers of cloth saturated with phenolic resin which have been compressed and cured to form an insulating material.

accelerating springs to force the switch points apart faster, increased travel of the breaker points, new trip mechanism levers, auxiliary switch, oil conservator and separator, enlarged capacity oil tank and dashpots to control actuating speed of mechanical components. All components are detailed in the Westinghouse Manual of Instructions and Renewal Parts for the Modernization of Circuit Breakers (Figure 8).

The modifications also included adding current transformers within the breakers. These devices constantly monitored amperage within the line. When current exceeded a preset limit, they would cause a relay to close, sending power to a solenoid (Photograph of closing solenoids) which opened a mechanical latch allowing the spring loaded moving contact to plunge away from the "de-ion" grid stationary contact and break the circuit (Figure 7).

Each section of track is fed through two breakers, one at each end. A time delay relay delays the opening of the breaker more distant from the fault. Breakers can be manually or automatically reset when the fault is cleared.

Following World War II, Westinghouse determined that the existing breakers were overrated, thus placing an excessive load on the equipment they were supposed to protect. A feeder breaker failed in 1942 and damaged the switch-house. Revising the breaker ratings required sectionalizing of the main buses, replacement of the station service bus, associated breakers and control room modifications. The work was accomplished under the direction of the engineering firm of Gibbs & Hill (Gibbs & Hill 1949:6). In the 1970s all circuit breakers were modified to operate on 60 cycle alternating-current and new protective relays were added. (Gilles 1994).

Technological Significance

The account of circuit breaker chronology gives several examples of innovative approaches to technical problems and their solution. With the available materials and equipment direct solutions were unavailable. When breakers failed because of increased current loads in the system, indirect approaches were implemented. The system was ingeniously modified to accommodate the weaknesses of the breakers. The engineering approach was pragmatic, practical and cost-effective.

The bridge-type circuit breakers have been operating for eighty-seven years. With proper maintenance they could continue to operate for many more years. However, the manufacturer no longer supplies repair parts or replaceable components. Replacement parts must be custom made in a machine shop. The cost of machining parts is not economic and has led to a decision to replace these units.

The long service life of these breakers is a tribute to effective design using simple, rugged components. It is also an acknowledgment of flexibility in design; the original housings were able to accept modifications based on technological improvements. The breakers kept pace with technology, increasing system loads and improved methods of system operation. They are a prime example of an elementary but vital system component that characterizes the role played by sound engineering design.

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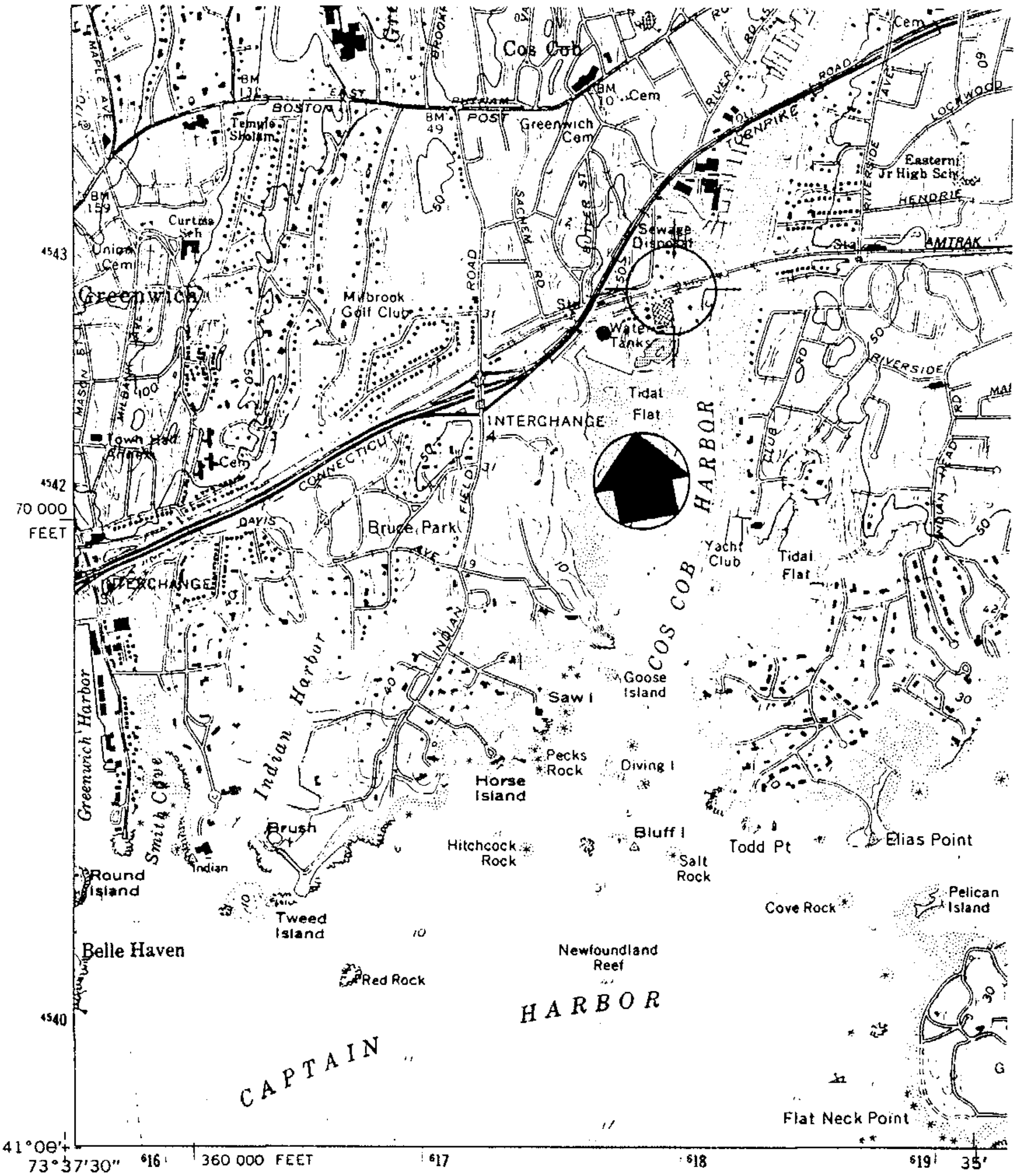
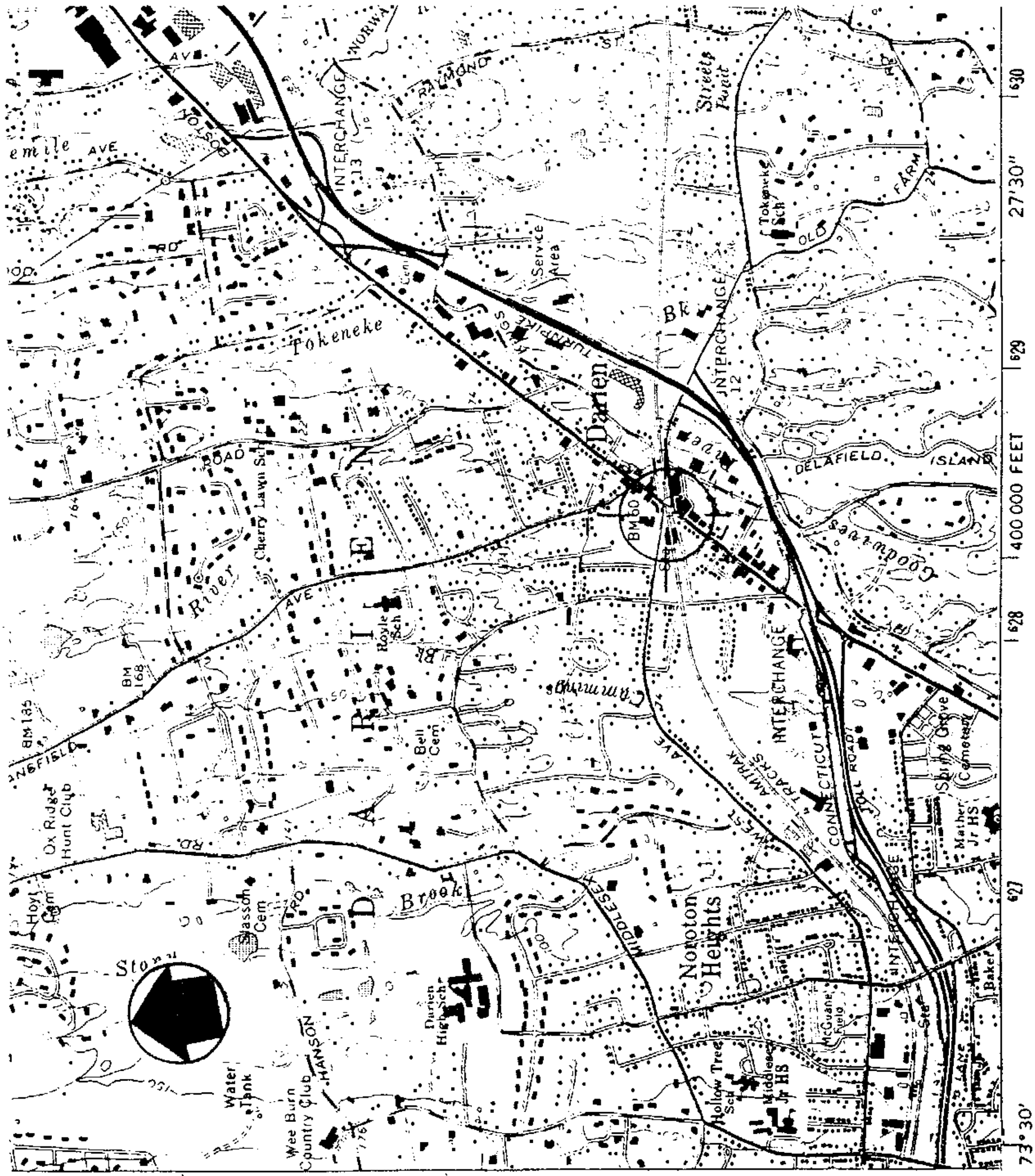
Location Map: Cos Cob - Anchor Bridge #310
Quadrangle: Stamford, Connecticut 1:24000



Location Map: Darien - Anchor Bridge #465
Quadrangle: Norwalk South, Connecticut 1:24000



Location Map: Stamford - Anchor Bridge #374
Quadrangle: Stamford, Connecticut 1:24000